Mon. Not. R. Astron. Soc. **000**, 000–000 (2003) Printed 2 February 2008 (MN LaTeX style file v1.4)

Temporal variability in early afterglows of short gamma-ray bursts

Zhuo Li[1,2⋆], Z. G. Dai[1†] and T. Lu[1‡]
[1]Department of Astronomy, Nanjing University, Nanjing 210093, China
[2]Particle Astrophysics Lab., Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100039, China

(*MNRAS* accepted)

ABSTRACT

The shock model has successfully explained the observed behaviors of afterglows from long gamma-ray bursts (GRBs). Here we use it to investigate the so-called early afterglows from short GRBs, which arises from blast waves that are not decelerated considerably by their surrounding medium. We consider a nearby medium loaded with $e^{\pm}$ pairs (Beloborodov 2002). The temporal behaviors show first a soft-to-hard spectral evolution, from the optical to hard X-ray, and then a usual hard-to-soft evolution after the blast waves begin to decelerate. The light curves show variability, and consist of two peaks. The first peak, due to the pair effect, can be observed in the X-ray, though too faint and too short in the optical. The second peak will be easily detected by *Swift*. We show that detections of the double-peak structure in the light curves of early afterglows are very helpful to determine all the shock parameters of short GRBs, including both the parameters of the relativistic source and the surroundings. Besides, from the requirement that the forward-shock emission in short GRBs should be below the BATSE detection threshold, we give a strong constraint on the shock model parameters. In particular, the initial Lorentz factor of the source is limited to be no more than $\sim 10^3$, and the ambient medium density is inferred to be low, $n \lesssim 10^{-1}$ cm^{-3}.

Key words: gamma-rays: bursts — radiation mechanisms: nonthermal — relativity

1 INTRODUCTION

It is recognized that gamma-ray bursts (GRBs) may be divided into at least two classes: one third of the bursts with short duration ($\lesssim 2$ s) and hard spectra, and the other two third with long duration ($\gtrsim 2$ s) and soft spectra (Kouveliotou et al. 1993; Dezalay et al. 1996; Paciesas et al. 2003). The detections of afterglows from long/soft GRBs and then their redshift measurements have revealed their cosmological origin (see van Paradijs et al. 2000 for a review). Their afterglows are widely believed to come from a blast wave driven by a relativistic ejecta into an ambient medium (see reviews of Cheng & Lu [2001] and Mészáros [2002]). Unfortunately, it is impossible so far for observations to systematically follow short GRBs at longer wavelengths. The effort of searching transient afterglow emission from short/hard GRB usually yields only some upper limits (e.g. Kehoe et al. 2001; Hurly et al. 2002; Gorosabel et al. 2002; Klotz, Boër & Atteia 2002). The difficulty for detection of short GRB afterglow is mainly due to the poor prompt localization by current satellites for these bursts. This problem is waiting for the upcoming *Swift* satellite to resolve. Lazzati, Remirez-Ruiz & Ghisellini (2001) report the discovery of a ~ 30 s delayed, transient and fading hard X-ray emission in the BATSE light curves of a sample of short GRBs, the soft power-law spectrum and the time-evolution are consistent with predicted by the afterglow model.

Based on the widely accepted blast wave model, Panaitescu et al. (2001) studied the long-term afterglows of short GRBs coming from the blast waves. In this paper, we focus on the investigation of early afterglow emission, which arises from the blast wave before it transits to the self-similar evolution in the ambient medium (Blandford & McKee 1976). We consider pair loading in the external medium, which is caused by the collision between the outgoing gamma-rays and the scattered photons off the ex-

⋆ lizhuo@mail.ihep.ac.cn
† daizigao@public1.ptt.js.cn
‡ tlu@nju.edu.cn

ternal medium (Madau & Thompson 2000; Thompson & Madau 2000; Dermer & Böttcher 2000; Madau, Blandford & Rees 2000; Mészáros , Ramirez-Ruiz & Rees 2001; Beloborodov 2002; Ramirez-Ruiz, MacFadyen & Lazzati 2002). The pairs will affect the behavior of early afterglows. As the short GRBs have ~ 20 times less fluence than long GRBs (Mukherjee et al. 1998), the kinetic energy of short GRBs must be ~ 20 times less than long GRBs too, provided that the efficiencies for producing gamma-rays are the same for both classes (Panaitescu & Kumar 2001). We take the typical kinetic energy of short GRBs as 10^{52} ergs here. Furthermore we assume that the shocks in short GRBs have parameters similar to those of long GRBs, except for the ambient density which is believed to be lower if short GRBs originate from the compact binary mergers (Eichler et al. 1989; Narayan, Paczyński & Piran 1992). Later on we will show that low density for a short GRB is required (eq. (17) and discussions below). In section 2 we discuss the hydrodynamics of short GRBs, and in section 3, pair loading in the external medium. An early afterglow from the blast wave is derived in section 4. Section 5 gives conclusions and observational implications.

2 HYDRODYNAMICS OF SHORT GRBS

A GRB itself is believed to come from internal shocks which are due to different Lorentz factors of shells within the ejecta (Rees & Mészáros 1994). After producing GRB the ejecta cools down rapidly and may be considered as a cold shell. The interaction between the outgoing shell and ambient medium leads to two shocks: a forward shock propagating into the medium, a reverse shock sweeping up the ejecta matter, and a contact discontinuity separating the shocked ejecta matter and the shocked medium. So the kinetic energy of the ejecta can be dissipated into the internal energy of the medium by the forward shock and into the internal energy of the ejecta matter by the reverse shock. According to Sari (1997), there are two time scales. One is relevant to the forward shock, at which the shell reaches an deceleration radius where the shell has given the medium an energy comparable to its initial energy,

$$t_{\rm dec} = 45 E_{k,52}^{1/3} \eta_{300}^{-8/3} n_{-2}^{-1/3} \left(\frac{1+z}{2}\right) \text{ s}, \tag{1}$$

where $E_k = 10^{52} E_{k,52}$ ergs and $\eta = 300\eta_{300}$ are the fireball kinetic energy and initial Lorentz factor, $n = 0.01 n_{-2}$ cm^{-3} is the particle density of the ambient medium, and z is the source's redshift. The other is relevant to the reverse shock, at which the reverse shock accelerates to become relativistic. The ratio between the two time scales is defined as

$$\xi = 12 E_{k,52}^{1/6} \left(\frac{\Delta}{3\times 10^9 \text{cm}}\right)^{-1/2} \eta_{300}^{-4/3} n_{-2}^{-1/6}, \tag{2}$$

where Δ is the shell width (in observer frame) of the ejecta. In the internal-shock model the shell width is $\Delta = cT = 3\times 10^9 T_{-1}$ cm, with $T = 0.1 T_{-1}$ s the duration of GRB. Eq. (2) shows that ξ is not sensitive to E_k and n, and only somewhat dependent on η which is not accepted to be quite larger than 10^3 (implied from eq.[17] below, and also implied from other aspects of GRBs, e.g., Lazzaiti, Ghisellini & Celotti 1999; Derishev, Kocharovsky & Kocharovsky 2001). Thus, for short GRBs, we usually have $\xi > 1$. In this case, the reverse shock is initially Newtonian and becomes mildly relativistic when it crosses the shell at $t_{\rm dec}$. Consequently the shocked medium has most of the initial energy, and the forward shock goes into the self-similar Blandford-McKee (1976) evolution.

3 PAIR LOADING IN GRB MEDIUM

The GRB itself from internal shocks is emitted early, preceding the development of the blast wave. The gamma-ray front interacts with the ambient medium, leading to two processes: Compton scattering and $\gamma-\gamma$ absorption of the scattered photons. As a result the medium is loaded with $e^{\pm}$ pairs within a loading radius $R_{\rm load} = 5\times 10^{15} E_{\gamma,52}^{1/2}$ cm, with $E_\gamma = 10^{52} E_{\gamma,52}$ ergs the isotropically explosive energy in gamma-rays (Beloborodov 2002). Approximately 10^3 pairs per ambient electron can be created when conditions are right, but usually it is much less, $f_0 \equiv N_\pm/N(R_{\rm load}) = 10^2 f_{0,2}$ (Beloborodov 2002). Therefore, the mass of $e^\pm$ pairs ahead of the blast wave is neglected, $f_0 < m_p/m_e$, it dose not affect the dynamics of the blast wave. Besides, the pairs may be pre-accelerated by the gamma-ray front, but the pair energy does not exceeds the ejecta kinetic energy. Provided that the medium density is low and the deceleration occurs outside the pre-accelerated radius $R_{\rm acc}$ (Beloborodov 2002) which is smaller than $R_{\rm load}$, the deceleration time (eq.[1]) will be not affected (Note however that as shown by Beloborodov [2002], for dense enough medium $t_{\rm dec}$ changes whenever deceleration occurs in a pre-accelerated medium, i.e., $R_{\rm dec} < R_{\rm acc}$). Typically, the deceleration time is longer than the one at which the blast wave approaches $R_{\rm load}$,

$$t_{\rm load} = \frac{R_{\rm load}(1+z)}{2\eta^2 c} = 1.7 E_{\gamma,52}^{1/2} \eta_{300}^{-2} \left(\frac{1+z}{2}\right) \text{ s}, \tag{3}$$

and the one at which the blast wave crosses a radius, $R_f = f_0^{1/3} R_{\rm load}$ where the number ratio (f) of the pair to ambient electron number drops to $f = 1$,

$$t_f = 7.9 E_{\gamma,52}^{1/2} \eta_{300}^{-2} f_{0,2}^{1/3} \left(\frac{1+z}{2}\right) \text{ s}. \tag{4}$$

Thus, for short GRBs we have the order, $t_{\rm load} < t_f < t_{\rm dec}$.

Here, when introducing radius R_f, we have assumed mixing of particles in the blast wave that allows the newly added post-shock particles to share energy with earlier injected pairs. Before the reverse shock crosses the ejecta and vanishes at $t_{\rm dec}$, the existence of the contact discontinuity prevents the earlier pairs from being far downstream the forward shock front. The total shocked mediums are compressed between the contact discontinuity and the forward shock front. Furthermore, the coupling of leptons with baryons may take place in presence of even weak magnetic fields (e.g. Madau & Thompson, 2000; Meszaros, Ramirez-Ruiz & Rees 2001), therefore the total particles are possible to be mixing, allowing continuous transmission of energy

from baryons to leptons. We will take the mixing hypothesis in the following.

4 EARLY AFTERGLOWS OF SHORT GRBS

We now derive the temporal property of early afterglows from forward shocks of short GRBs. We consider the source as an isotropic explosion even though it may have jet geometry, because the jet effect is not important at early times when the jet open angle is larger than $\sim 1/\eta$.

4.1 Phase $t_{\rm load} < t < t_f$

We begin with the blast wave having swept up all the produced pairs at $R_{\rm load}$. The pairs will modify the usual property of the afterglow, since the same energy will be shared by much more leptons. Furthermore the pairs will increase the radiation efficiency significantly. With the mixing hypothesis, the comoving-frame random lepton Lorentz factor is

$$\gamma_m = \frac{m_p}{(1+f)m_e}\epsilon_e \eta. \tag{5}$$

Here, $f \equiv N_\pm/N_e$, and the energy density in leptons and magnetic field $\frac{B^2}{4\pi}$ behind the shock are usually parameterized by the fractions $\epsilon_e = 0.1\epsilon_{e,-1}$ and $\epsilon_B = 0.01\epsilon_{B,-2}$ of the total internal energy density ($\eta^2 n m_p c^2$), respectively. For $f > 1$ at $t_{\rm load} < t < t_f$, this Lorentz factor is a factor $(1+f) \approx f$ lower than usual case, and the corresponding synchrotron frequency is therefore

$$\nu_m = 1.8\times 10^{14}\epsilon_{e,-1}^2 \epsilon_{B,-2}^{1/2}\eta_{300}^4 n_{-2}^{1/2} f_2^{-2}\left(\frac{1+z}{2}\right)^{-1}\ \mathrm{Hz}, \tag{6}$$

which is in the optical band if $f = f_0 = 10^2 f_{0,2}$ at $t_{\rm load}$, as opposed to the hard X-ray of the usual case. Now the pair number dominates the ambient electron's number, the total lepton number is $N_{\rm lep.} \simeq \frac{4}{3}\pi R_{\rm load}^3 n f_0$. The peak spectral power (in comoving frame) per lepton is $P_{\nu,\max} = 1.4\times 10^{-22} B$ ergs s^{-1}Hz^{-1}. We then have the afterglow peak flux

$$\begin{aligned} F_p &= N_{\rm lep.}\eta P_{\nu,\max}\frac{(1+z)}{4\pi d_l^2} \\ &= 3.2\epsilon_{B,-2}^{1/2}E_{k,52}^{3/2}\eta_{300}^2 n_{-2}^{3/2} f_{0,2} d_{l,28}^{-2}\left(\frac{1+z}{2}\right)\mu\mathrm{Jy} \end{aligned} \tag{7}$$

where $d_l = 10^{28} d_{l,28}$ is the GRB's luminosity distance. To calculate the synchrotron spectrum, we still need to know the cooling frequency that is corresponding to those leptons which cool by synchrotron/inverse-Compton radiation in a dynamical time t, i.e.

$$\nu_c = 2.5\times 10^{20}\epsilon_{B,-2}^{-3/2}\eta_{300}^{-4} n_{-2}^{-3/2} t^{-2}\left(\frac{1+Y}{2}\right)^{-2}\left(\frac{1+z}{2}\right)\ \mathrm{Hz}, \tag{8}$$

where Y is the Compton parameter. According to Panaitescu & Kumar (2000), $Y = \frac{1}{2}\{[\frac{5}{6}(\epsilon_e/\epsilon_B)+1]^{1/2}-1\} \approx 1$. Now for observer's time $t = t_{\rm load}$,

$$\nu_c(t_{\rm load}) = 3.4\times 10^{20}\epsilon_{B,-2}^{-3/2}E_{\gamma,52}^{-1} n_{-2}^{-3/2}\left(\frac{1+z}{2}\right)^{-1}\ \mathrm{Hz}. \tag{9}$$

The synchrotron spectrum from leptons distributed as $dN_{\rm lep.}/d\gamma_e \propto \gamma_e^{-p}$ ($\gamma_e > \gamma_m$) is a broken power-law with break frequencies ν_m and ν_c: $F_\nu \propto \nu^{1/3}$ at $\nu < \nu_p \equiv \min(\nu_m, \nu_c)$; $F_\nu \propto \nu^{-1/2}$ for $\nu_c < \nu < \nu_m$ or $F_\nu \propto \nu^{-(p-1)/2}$ for $\nu_m < \nu < \nu_c$; and $F_\nu \propto \nu^{-p/2}$ at $\nu > \max(\nu_m, \nu_c)$ (Sari, Piran & Narayan 1998). Here we neglect the synchrotron self-absorption which is only important at longer wavelengths, e.g., radio or IR.

Since $f \propto N_e^{-1} \propto R^{-3} \propto t^{-3}$, eq.(6) implies that the peak frequency rapidly increases, as $\nu_m \propto t^6$, from the optical to the hard X-ray band eventually (eq.[13]). Thus, we have the scaling laws for $t_{\rm load} < t < t_f$,

$$F_p = \mathrm{const.},\quad \nu_m \propto t^6,\quad \nu_c \propto t^{-2}\quad (t_{\rm load} < t < t_f). \tag{10}$$

The afterglow shows a soft-to-hard spectral evolution during this phase. Observed at a fixed frequency, $\nu_{\rm ob}$, between the optical and hard X-ray, the light curve will show a rapidly increase, $F_\nu \propto t^{3(p-1)}$, and then a sharp decreasing, $F_\nu \propto t^{-2}$, after ν_m crosses $\nu_{\rm ob}$ at

$$t_{pk} = 4.9\frac{\nu_{\rm ob,17}^{1/6}E_{\gamma,52}^{1/2} f_{0,2}^{1/3}}{\epsilon_{e,-1}^{1/3}(\epsilon_{B,-2} n_{-2})^{1/12}\eta_{300}^{8/3}}\left(\frac{1+z}{2}\right)^{7/6}\ \mathrm{s}. \tag{11}$$

4.2 Phase $t_f < t < t_{\rm dec}$

outside R_f, we have $f < 1$, implying that pair effect is negligible. The afterglow property then approaches the usual case, where

$$F_p \propto N_e \propto t^3,\quad \nu_m = \mathrm{const.},\quad \nu_c \propto t^{-2}\quad (t_f < t < t_{\rm dec}). \tag{12}$$

In details,

$$\nu_m = 1.8\times 10^{18}\epsilon_{e,-1}^2\epsilon_{B,-2}^{1/2}E_{k,52}\eta_{300}^4 n_{-2}^{1/2}\left(\frac{1+z}{2}\right)^{-1}\ \mathrm{Hz} \tag{13}$$

is a constant and should be in the hard X-ray band. The cooling frequency continues to decrease (eq.[8]) to

$$\nu_c(t_{\rm dec}) = 5.0\times 10^{17}\epsilon_{B,-2}^{-3/2}E_{k,52}^{-2/3}\eta_{300}^{4/3} n_{-2}^{-5/6}\left(\frac{1+z}{2}\right)^{-1}\ \mathrm{Hz} \tag{14}$$

at $t = t_{\rm dec}$. Note that $\nu_m > \nu_c(t_{\rm dec})$, implying that ν_c has crossed ν_m at a certain moment t_{cm} after which the spectrum becomes peaking at ν_c, which is in X-rays. Due to ambient electrons picked up, the peak flux increases rapidly to

$$F_p(t_{\rm dec}) = 580\epsilon_{B,-2}^{1/2}E_{k,52} n_{-2}^{1/2} d_{l,28}^{-2}\left(\frac{1+z}{2}\right)\mu\mathrm{Jy} \tag{15}$$

at $t = t_{\rm dec}$. If observing at a fixed sub-keV frequency, we can see in this phase the light curve climbing up again.

Now a constraint on short GRBs arises from the requirement that the flux in sub-MeV should not exceed the BATSE detection threshold. Otherwise, as $t_{\rm dec} > 2$ s, the burst is not short any more. With $n = 0.01$ and other parameters in their typical value, we obtain the flux given by

$$\begin{aligned} \Phi(\mathrm{MeV}) \simeq\ & 2\nu_m F_{\nu_m} = 2(\nu_m\nu_c)^{1/2} F_p = 1.1\times 10^{-8} \\ & \times\epsilon_{e,-1}E_{k,52}^{2/3}\eta_{300}^{8/3} n_{-2}^{1/3} d_{l,28}^{-2}\mathrm{ergs\ cm^{-2}s^{-1}}. \end{aligned} \tag{16}$$

We set that the BATSE threshold is 1×10^{-8} ergs cm^{-2}s^{-1}, leading to a constraint on the "short GRB" parameters of

$$\epsilon_{e,-1}E_{k,52}^{2/3}\eta_{300}^{8/3} n_{-2}^{1/3} d_{l,28}^{-2} < 1. \tag{17}$$

Note that the most stringent constraint is on η, which is not allowed to be too large, i.e. $\eta \lesssim 10^3$. A lower limit to η arises from the requirement that during the prompt sub-MeV burst, the optical depth due to scattering off fireball electrons, $\tau_b = \sigma_T N_b / 4\pi R_\gamma^2$, should be less than unity (Rees & Mészáros 1994), with $N_b = E_k/\eta m_p c^2$ the fireball baryon number, $R_\gamma \leq \eta^2 c\delta t$ the radius at which the fireball kinetic energy dissipated to gamma rays, and δt the shortest time scale of rapid variability in the GRB profile. This leads to $\eta > 330 E_{k,52}^{1/5} \delta t_{-2}^{-2/5}$, thus the η value taken in eq. (17) is to the lower limit. If the other parameters are fixed to their typical values, the ambient density for short GRBs is limited to $n \lesssim 0.01$ cm^{-3} (eq. [17]), consistent with the clean-environment hypothesis to short GRB models of compact binary systems, e.g. Eichler et al. (1989); Narayan, Paczyński & Piran (1992).

4.3 Phase $t > t_{\rm dec}$

In this phase, the blast wave begins to decelerate considerably. If the electrons obtain a significant fraction of total energy, $\epsilon_e \sim 1$, the blast wave will evolve in the radiative regime, since all the electrons are fast cooling, with $\nu_c < \nu_m$. The light curve is somewhat complicated in this case with light-curve index related to ϵ_e (Böttcher & Dermer 2000; Li, Dai & Lu 2002). For the typical value $\epsilon_e = 0.1$, we can safely consider a adiabatic blast wave, so the well know scaling laws are:

$$F_p = \text{const.}, \quad \nu_m \propto t^{-3/2}, \quad \nu_c \propto t^{-1/2} \quad (t > t_{\rm dec}), \tag{18}$$

where F_p is given by eq.(15). The afterglow spectrum shows the usual hard-to-soft evolution after $t_{\rm dec}$. Observed at a certain frequency $\nu_{\rm ob}$ between the optical and keV band, when ν_m or ν_c crosses $\nu_{\rm ob}$, whichever the first, the observed flux reaches a peak with $F_{\rm ob} = F_p \simeq 580\mu$Jy. It is a magnitude $\simeq 15.6$ if observed in the optical. Thus, there is another peak in the light curve other than the first one in the phase $t < t_f$. Furthermore, this second peak is much stronger than the first one. Lazzati, Remirez-Ruiz & Ghisellini (2001) claim to have detected such a delayed hard X-ray peak.

In Fig. 1 we show the light curves at two bands, the optical and the X-ray, also labelled in this figure are the characteristic times and the light-curve scaling laws.

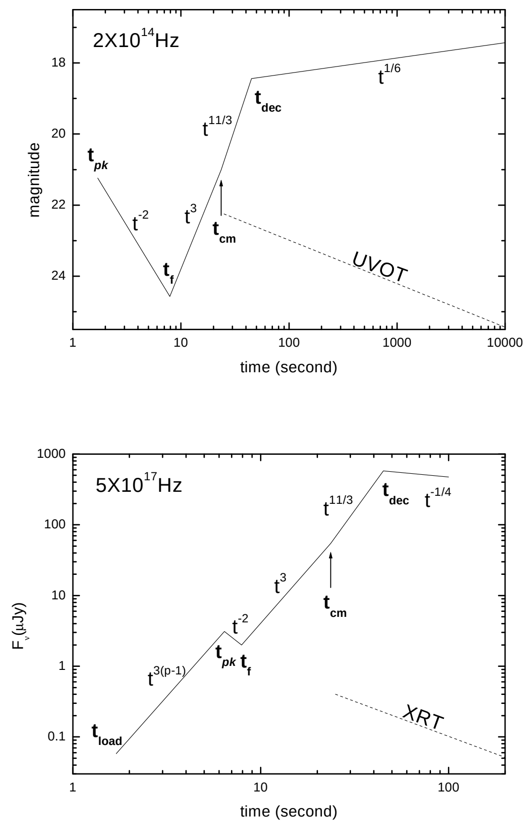

Figure 1. Example of early afterglows of from short GRBs at two fixed frequencies, $\nu = 2 \times 10^{14}$ (*upper frame*) and 5×10^{17} (*bottom frame*) Hz. The parameter values taken to calculate the light curves are: $E_\gamma = E_k = 10^{52}$ ergs, $n = 0.01$ cm^{-3}, $f_0 = 10^2$, $p = 2$ and the others equal to typical values of long GRBs (see details in the text). The characteristic times and the scaling laws of fluxes with time are marked. The dashed lines show the sensitivity of *Swift* instruments, the X-ray (XRT) and UV optical (UVOT) Telescopes.

5 CONCLUSION AND DISCUSSION

Based on the shock model which has been essentially successful to explain long GRB afterglows, we here derive the light curves of short GRB afterglows in the early phase when the blast wave is not decelerated by the ambient medium considerably. The reverse-shock emission has been ignored at the beginning since it is always Newtonian initially for short GRBs. We consider the pair-loading effects on the emission. The spectrum shows rapid soft-to-hard evolution at the first several seconds ($t < t_f$), and then a usual hard-to-soft evolution after several tens of seconds ($t > t_{\rm dec}$). Simultaneously, there are two peaks appearing in the light curves in the optical to hard X-ray range. The first "pair peak" will appear at the optical, but it is too faint (mag ~ 21) and too short (~ 2 s) to be detected by any current and upcoming instrument. But the double-peak structure in the light curve is expected to be observed at X-ray band: the first peak at t_{pk} and the second peak at around $t_{\rm dec}$. It took only 20 to 70 s for *Swift* to point its Narrow Fields instruments, consisting of X-ray and UV optical Telescopes, to the GRB direction, short GRBs will be easily detected before the second peak (Fig. 1). The recently proposed micro-satellite *ECLAIR* (Barret 2003) is even expected capable of detecting the first peak.

Though the reverse shock becomes mildly relativistic finally at $t_{\rm dec}$, we have neglected its emission here, which is mainly in the soft band, say, the optical. If we consider further the effect of pair-loading in the fireball which due to $\gamma - \gamma$ absorption of the prompt burst in the fireball, it would be in much softer band such as in the IR. Because the same energy may be shared by more produced $e^\pm$ pairs, the lower-energy leptons would radiate at softer frequency.

So the reverse-shock emission will not affect the X-ray lightcurve, though may affect the optical one.

The blast wave emission in sub-MeV must be under the BATSE detection threshold for short GRBs. Provided that the energy is $E_k = 10^{52}$ ergs, and $\epsilon_{e,-1} = d_{l,28} = 1$ similar to typical values of long GRBs, we find a constraint on initial Lorentz factor and ambient density of $\eta_{300}^{8/3} n_{-2}^{1/3} < 1$ (cf.eq.[17]), and that the Lorentz factor of short GRBs is not allowed to be large, i.e., $\eta < 10^3$. This also limit the ambient density to $n \lesssim 0.1$ cm^{-3}, which is consistent with upper limit on late-time short GRB afterglows. So far, the best constraint on short GRB afterglows comes from the observation of short/hard GRB 020531, which yields the limiting magnitudes in R band: 18.5 at 88 min and 25.2 at 2.97 d (Klotz et al. 2002). Under a standard afterglow model, these data do not allow for a dense medium, i.e. $n \lesssim 0.1$ cm^{-3} (see Fig. 2 in Panaitescu et al. 2001). Low densities favor the GRB model related to compact object mergers (Eichler et al. 1989; Narayan, Paczyński & Piran 1992) in galactic haloes or in the intergalactic medium.

At $t_{\rm load}(> 2$ s) the optical photons in the pulse may be up-scattered to MeV by synchrotron self-Compton process. But the flux is of orders lower than BATSE detection threshold, and is unable to change the short-duration property of short GRBs.

Unlike the long GRBs which may overlap the early afterglows and lead to complication, the short GRBs stop abruptly. And due to lower ambient density the blast waves take longer time to begin decelerating considerably, so their early afterglows are easy to be observed. If detected and confirmed, the double-peak structure in early afterglows has an important indication for short GRBs — with redshift having been measured, we can determine the most important parameter η from eqs.(4) and (11) (Beloborodov 2002), and then we can further use the value of η to constraint the other parameters, E_k and n, by eq.(1). So an observation of early afterglows provides important constraints on the short GRB parameters, related both to the relativistic flow and to the surroundings.

ACKNOWLEDGMENTS

We would like to thank the referee for valuable comments. Z. Li thanks X.Y. Wang for valuable discussions and R.F. Shen for careful reading. This work was supported by the National Natural Science Foundation of China, the National 973 Project (NKBRSF G19990754) and the Special Funds for Major State Basic Research Projects.

REFERENCES

Barret, D. 2003, AIP Conf. Proc. 662, preprint (astro-ph/02053476)
Beloborodov, A. M., 2002, ApJ, 565, 808
Blandford, R. D., & McKee, C. F. 1976, Phys. Fluids, 19, 1130
Böttcher, M., & Dermer, C. D. 2000, ApJ, 532, 281
Cheng, K. S. & Lu, T. 2001, Chin. J. Astron. Astrophys., 1, 1
Derishev, E. V., Kocharovsky, V. V., & Kocharovsky, Vl. V., 2001, A&A, 372, 1071
Dermer, C., & Böttcher, M., 2000, ApJ 534, L155
Dezalay J. P., Lestrade J. P., Barat C., Talon R., Sunyaev R., Terekhov O., Kuznetsov A., 1996, ApJ, 471, L27
Eichler D., Livio M., Piran T. & Schramm D. N., 1989, Nat, 340, 126
Gorosabel, J., et al. 2002, A&A, 383, 112
Hurley, K. et al. 2002, ApJ, 567, 447
Kehoe, R., et al. 2001, ApJ, 554, L159
Klotz, A., Boër, M., & Atteia, J. L. 2002, A&A, 404, 815
Kouveliotou C., Meegan C. A., Fishman G. J., Bhat N. P., Briggs M. S., Koshut T. M., Paciesas W. S., Pendleton G. N., 1993, ApJ, 413, L101
Lazzati, D., Ghisellimi, G., & Celotti, A., 1999, MNRAS, 309, L13
Lazzati, D., Ramirez-Ruiz, E., & Ghisellimi, G. 2001, A&A, 379, L39
Li, Z., Dai, Z. G., & Lu, T. 2002, MNRAS, 330, 955
Madau, P., Blandford, R., & Rees, M. J., 2000, ApJ, 541, 712
Madau, P., & Thompson, C., 2000, ApJ, 534, 239
Mészáros , P. 2002, ARA&A, 40, 137
Mészáros , P., Ramirez-Ruiz, E., & Rees, M. J., 2001, ApJ, 554, 660
Mukherjee S, Feigelson E. D., Jogesh Babu G., Murtagh F., Fraley C., Raftery A., 1998, ApJ, 508, 314
Narayan, R., Paczyński , B., & Piran, T., 1992, ApJ, 395, L83
Paciesas W. S., Briggs M. S., Preece R. D., Mallozzi R. S., 2003, AIP Conf. Proc. 662, preprint (astro-ph/0109053)
Panaitescu, A., & Kumar, P., 2000, ApJ, 543, 66
Panaitescu, A., Kumar, P., & Narayan, R. 2001, ApJ, 561, L171
Ramirez-Ruiz, E., MacFadyen, A. I., & Lazzati, D. 2002, MNRAS,331, 197
Rees, M.J. & Mészáros, P. 1994, ApJ, 430, L93
Sari, R. 1997, ApJ, 489, L37
Sari, R., Piran, T., & Narayan, R. 1998, ApJ, 497, L17
Thompson, C., & Madau, .P, 2000, ApJ, 538, 105
van Paradijs, J., Kouveliotou, C., & Wijers, R. A. M. J. 2000, ARA&A, 38, 379